THE DIALOGUE BETWEEN ANCIENT AND MODERN MATERIALS IN THE RESTORATION OF A COLLAPSED ANCIENT CHAPEL

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ABSTRACT

While facing a restoration of an ancient building, sometimes a reconstruction is needed. The decision to use modern materials could be quite conflictive, especially when the building is to be in use once again and the visitors see the outcome. This was the case of the Chapel of the Holy Sepulchre, Orihuela (Alicante). It was built as a satellite cult place from the abbey of San Francisco, and it was placed as a Calvary at the top of a hill close to the main building. Over the years, this building became part of the neighbourhood's identity and one of the most important anchor points for the inhabitants of the area.

Neglected maintenance made the building collapse at the end of the 1990s. The City Council of Orihuela acquired the building in 2007 and planned to restore it, but architects faced a problem regarding restoration, as most parts of the building had collapsed.

The restoration process of the chapel, especially in terms of structure, is based on the relation between modern and traditional materials, a final touch that did not change the feeling of identity that the inhabitants once had over the original chapel.

Keywords: heritage and debate, restoration, restoration techniques, structural reinforcement.

1 INTRODUCTION

The overall value of a building is not limited solely to its economic, artistic, technical or historical merits. A building is part of an urban network, where many activities take place and, at the same time, it creates strong links with the subjective part of the inhabitants' life. Some of these buildings, the oldest or the most used, become anchor points for those who lived close by and reinforce the need to maintain history and tradition in order to reach a healthy urban environment. Historical legacy is necessary for citizens' lives and allows them to face future challenges. The loss of a building of historical, cultural and artistic value is not only a material fact, but it most importantly results in the loss of collective identity, which is never to be restored [1].

The restoration of the Chapel of the Holy Sepulchre was intensely demanded by those who lived close by. The restoration works of the building, originally built in the first-third of the 18th century, provide a good example of the need for recovering architectural heritage and, at the same time, a dialogue between modern and ancient constructive techniques.

2 THE CHAPEL

The chapel known as the Holy Sepulchre was placed at the top of a hill close to the main entrance to the abbey of San Francisco and acted as a Calvary to where Via Crucis and other religious activities were periodically organized in Orihuela [2].

Orihuela, the former capital city of the region, head of the bishopric since the 16th century, has many churches, abbeys and chapels. Its urban development has always been tied to the creation of new cult places, which were the starting point for new neighbourhoods [3].

The lack of maintenance made the chapel collapse in part at the end of the 1990s (Fig. 1). The City Council of Orihuela acquired the building in 2007 and planned to recover it as a

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Figure 1: Condition of the chapel in 2009.

cultural building that could increase and balance the level of urban activity in the neighbourhood. The RGBG Strategic Plan [4], a graphical urban analysis tool, developed during the revision of the master plan of the city, showed the intense relationship between the main abbey building and the chapel and the great value of both buildings inside the urban frame was also manifested as providers of cultural activity.

3 DESCRIPTION OF THE CHAPEL

The building was constructed in a neo-classic style, and the layout is in the form of a Latin cross. It has only one nave with a slightly pronounced transept, which terminates in a polygonal apse corresponding to the main altar. Adjoining the main nave, there is a smaller room built in the same structural type, originally covered by a dome roof with Arabic tiles, which functioned as the sacristy. Bays open along the central nave, the sides of the presbytery and inside the sacristy to let the light in.

The Chapel roof presented three different typologies: the nave had a gable roof made up of a barrel vault with transverse arches and lunettes, brick partition walls, a brick layer over them and flat tiles. A semi-spherical dome resting over four toral arches, with half-round Arabic roof tiles, topped the transept.

The original structural system of the Chapel consisted of masonry load-bearing walls that defined the central nave. These walls supported the weight of the arches that in turn supported the vault and the dome.

It seems that during the construction, some structural problems appeared, as two extra structures were added to the main body [5]. Two adjoining houses, one on either side, were constructed in order to compensate horizontal loads that were causing damages in the vaults of the main nave. Over time, these two constructions played an important structural role by keeping the load-bearing walls of the chapel intact and preventing structural collapse.

4 THE BUILDING BEFORE INTERVENTION AND ANALYSIS OF DAMAGES

At the time of intervention, the Chapel of the Holy Sepulchre was under structural failure and a total collapse process (Fig. 2). Although some repairs were carried out in previous years, they were unfortunately carried out and, in some cases, worsened the damage.

The roofs, structural elements and adjoining buildings were in a state of deterioration and ruin. The deterioration of the adjoining buildings, which for decades had contributed to the stability of the structure, generated significant deformations of the main vault and the dome. This caused movements, opened cracks in key parts of the arches and made them lose stability

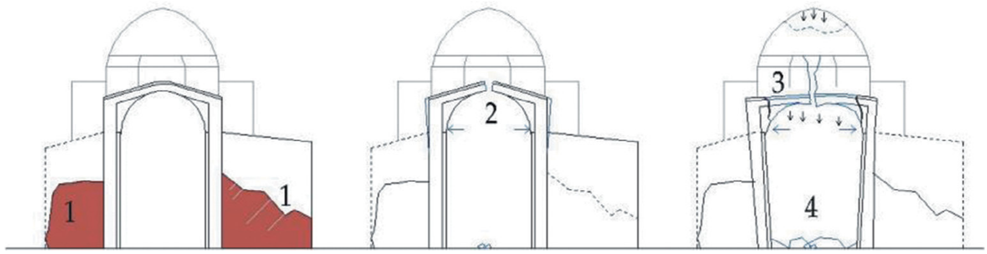


Figure 2: Collapsing process cross section. 1. Adjoining buildings collapse. 2. Load-bearing walls movement. 3. Damage at toral arches. 4. Vaults collapse.

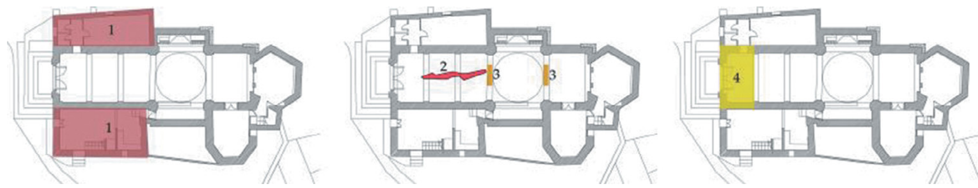


Figure 3: Collapsing process floor plan. 1. Adjoining buildings ruin. 2. Vaults collapse. 3. Damages at toral arches. 4. Choir room collapse.

(Fig. 3). These damages occurred in the main axe of the nave, from the main entrance to the dome, just in the area adjoining the buildings [6].

The lack of maintenance of the roofs adversely affected the permeability of the building. The water infiltration caused materials to become damp and increase in weight. Because of the initial deformation, the damages in the adjoining buildings, and the additional excess weight, the load-bearing walls continued to move, the cracks in the arches widened and the vault started to collapse. The collapse of the chapel started with the section of the vault closer to the dome and finished at the section closer to the main entrance that, dragging the choir room down with it, fell down just before the restoration started. The dome, however, remained standing, but in a very dangerous state, as two of the four supporting arches were out of use and the dome was resting over the other two only (Fig. 4).

Besides the structural damages, the chapel also suffered problems in the interiors because of the humidity that was growing up from the lower part of the load-bearing walls. This damage was deteriorating interior coatings, solved with gypsum-lime mortars. Some frescoes, which were painted around the main altars, suffered both infiltration of water from the roof and humidity of the walls added to unfortunate restorations that caused them to be in very bad conditions.

5 INTERVENTION APPROACH

Designing a building restoration is always a difficult task, especially when there are many elements beyond repair. Moreover, demolishing parts of a historical building is always fraught with conflict. On the other hand, legacy must be considered when thinking about future generations, and among the different restoration techniques, the one which better fits to the current state of the building must be chosen. The special characteristics and the condition of the chapel made the architects approach restoration by preserving those constructive elements that still remained standing, discarding only those which were beyond repair. These parts of the building would be restored in an identical style to the original, with similar constructive

Figure 4: Detail of the dome, the supporting arches and frescoes.

techniques and removing redundant elements. On the other hand, restoration approach for those areas beyond repair would be done by differentiation, in such a way that it would remain clearly evident which elements and materials were original and which had been reconstructed during the intervention. The reconstructed elements would be built using modern construction and structural techniques as it would be felt that this intervention should be considered part of the historical background of the building. The reconstructed elements should indicate to future visitors the state of the building and how the structural problems were resolved through the restoration works. This intervention should show future generations the scope of the work undertaken and the value placed on the age of the recovered and restored elements.

Analysing the chapel, the conservation status of one part of the vaults and both adjoining houses recommended a reconstruction approach because, in both cases, the structure had collapsed. The rest of the vaults, the load-bearing walls and the dome could receive a more conservative treatment.

6 STRUCTURAL CONSOLIDATION WORK

The most important and complex aspect of the intervention was to achieve structural consolidation of the building. It was essential to stop structural collapse, a state in which the chapel was, and to do this, it was crucial to restore the original stability. Analysis of how it was collapsing revealed how important both adjoining houses were and therefore it required reconstruction in order to recover their role as a stabilizing force against the horizontal thrust exerted by the vaults on the walls. In addition, it was imperative to ensure that these new buildings could stop the displacement of the load-bearing walls, which were significantly bowed.

It was also necessary to guarantee stability from the still-standing part of the building, dome and vaults, which, in this case, could be accomplished with complementary solutions to the existing load-bearing walls.

6.1 Reconstructing the adjoining houses

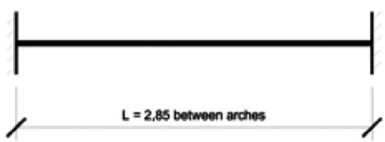
The condition of the first three bays of the vault was so dangerous that prior to demolition of the damaged materials, the remaining parts of the collapsed vaults and both side load-bearing walls needed to be reattached with the aim of preventing the walls from further buckling.

Once this part of the building was secured, the reconstruction of both adjoining houses carried out with a concrete structure started. The design of the structural system meant placing vertical reinforcements along the existing load-bearing walls acting as buttresses for protection against horizontal thrusts and to limit the current bowing movement (Fig. 5). The line of pillars along the walls was doubled with another one in the façade and was connected by beams dimensioned to absorb loads due to horizontal thrusts.

Topping the line of pillars along the walls, a flat beam was designed with the purpose of receiving the new vaults. Load-bearing walls were so bowed, over 0.70 m in verticality, that it was not possible to use them as a structure anymore and they could not support the new vaults. The designed structural system used the above-mentioned flat beam for supporting the new vaults and transmitting loads to the new adjoining structures.

Horizontal loads were supported by the new structure for the choir room, with an iron beam embedded through the new vault and with four stays at the lower part of the toral arches [7].

The reconstruction of the new vaults followed what was decided in the restoration approach, and it was categorized in the beyond repair group. The material chosen for its construction was reinforced concrete, and it was calculated in order to supporting horizontal loads. The section needed is obtained from the following calculations:



Estimated slab weight (8 cm) = 200 kp/m^2

$$M = 0.2 \cdot \frac{2.85^2}{16} = 0.1015 \text{ T·m/m·l}$$

$$\sigma = \frac{0.1015 \cdot 10^5 \cdot 6}{100\,.\,8^2} \quad 9.52 \text{ kp/cm}^2$$

$$9.52 \text{ kp/cm}^2 \ll f_{ct,k} \text{ (HA-25)}$$

Spanning between the arches, a 8-cm-thick concrete element supporting its own weight, can work without steel reinforcement, as its maximum tension is not over $f_{ct,k}$, that for a HA-25 concrete.

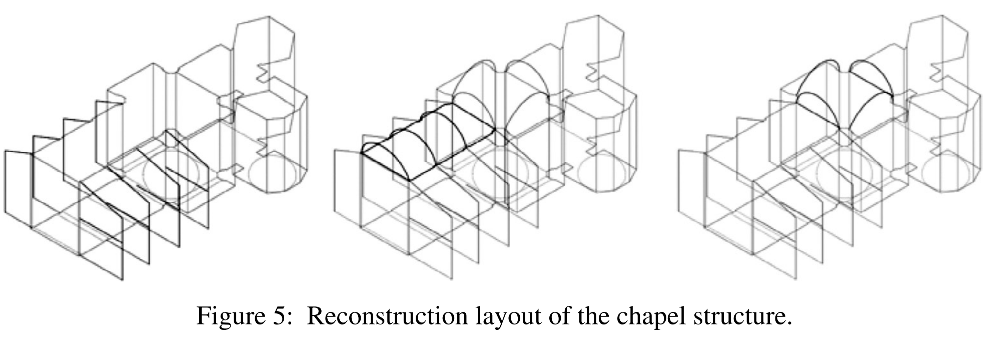


Figure 5: Reconstruction layout of the chapel structure.

Figure 6: Wooden form-works and new vault reinforcement.

$$f_{ct,k} = 0.7\, f_{C,m}$$
$$f_{ct,k} = 0.7 \cdot 0.3 \cdot \sqrt[3]{25^2}$$
$$f_{ct,k} = 1.79 \text{ MPa} = 17.9 \text{ kp/cm}^2$$

The shape of the vaults was obtained through wooden form-works that were copied from the original still-standing vault bays (Fig. 6). The concrete was not covered, and its grey colour was left as the final coating so that it could be identified as a reconstructed element.

6.2 Reinforcing the dome

Once the load-bearing walls of the Chapel were reinforced, works on the dome could begin. This hemispherical element rested over four supporting arches and their pendentives, all constructed with bricks, from which only two of them still had a structural function. As in the rest of the main nave of the chapel, horizontal loads were also present, and they must be balanced.

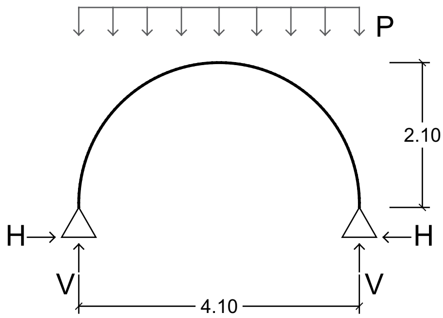
Reinforcement was achieved by complementary solutions to the existing constructive elements by banding the dome, reinforcing the supporting arches with concrete beams and installing four steel stays at the bottom of the two supporting arches parallel to the nave [8].

For calculating the stays, the following load estimations were assumed:

Dome supporting cylinder:	Estimated Thickness, ***e***	30 cm
	Height, ***H***	100 cm
	External Radius, ***Re***	270 cm
	Internal Radius, ***Ri***	240 cm
	Volume = $\pi \cdot (Re^2 - Ri^2) \cdot H =$	4.81 m^3
Dome:	Estimated Thickness, ***e***	25 cm
	External Radius, ***Re***	265 cm
	Internal Radius, ***Ri***	240 cm
	Volume = $\frac{2}{3}\pi \cdot (Re^3 - Ri^3) =$	10.0 m^3

Total Volume = 4.81 + 10.0 = 14.81 m^3

Weight = $V_T \cdot \gamma = 14.81 \cdot 2.30 = 34.10$ tons



$$P = \frac{34.1}{4} \cdot \frac{1}{4.1} = 2.08 \text{ T/m·l}$$

Once the loads were estimated, it was necessary to size the stays considering their position in the lower part of the supporting arches.

In order to make the arch work with compression loads and to avoid bending moments, *H* should be:

$$H = (P\bullet L\text{^}2)/(8\bullet f) = (2.08 \bullet((4.10)\text{^}2)/(8\bullet 2.10) = 2.08 \text{ tons}$$

In the stays design, in order to avoid fatigue, it is recommended not to trespass 45% of maximum tension resistance, so

$$\text{Tdesign} = 2.08/0.45 = 4.63 \text{ ton} \approx 5{,}000 \text{ kg}$$

Once the supporting structure of the dome was reinforced, materials damaged during a previous repair of the dome were removed and a restoration through replacement of part of the webbed part, using hollow ceramic bricks, was carried out (Fig. 7). A final reinforcement, mortar with a light iron net, was needed for supporting the cover and helped the construction of an eight-sided fluted dome, covered with Arabic roof tiles.

Figure 7: Reinforcement of the arches supporting the transept dome.

6.3 Reinforcing the rest of the vault

Works were also carried out on the still-standing vault lunette sections, as it had been decided to preserve them. However, because of the poor condition of the mortar holding the bricks of the webbed part, it was decided to reinforce these elements with cement mortar pointing from below [9].

Following completion of the reinforcement, the roofs were reconstructed, in this case, using flat Alicante tiles. This time, however, the building system was changed; the partition walls which supported the roof, built with heavy bricks, were eliminated in an attempt to reduce the resting weight as much as possible on the vault bays. The solution adopted consisted of installing an auxiliary metallic structure. Galvanized steel sandwich panels with polyurethane foam were laid on this structure, which would serve as the support for the roof tiles.

7 INTERIORS

The lack of maintenance affected the interiors from two sides: water coming from the roof and humidity growing from the bottom of the walls. Both lesions damaged the interior coatings, especially made from cal-gypsum mortars. Also, the various paintings over the walls suffered deeply with the presence of water. Reparation of the wall surfaces was carried out by eliminating particularly damaged areas and rendering a breathable mortar, which permits the rising damp to evaporate (Fig. 8). The same material was extended in the external walls. No paint was placed over the mortars and the material colour was left as final coating.

8 THE CHAPEL AFTER RESTORATION

The use of the chapel, as it was not a cult place anymore, was largely discussed by the city council. Finally, in order to introduce a new use within the neighbourhood, it was decided to transform it into an exhibition hall that could complement the cultural offer of the city.

The restoration of the chapel showed visitors a dialogue between two intervention techniques, one inclusive and another one that contrasts, showing which parts of the chapel were reconstructed (Fig. 9).

This restoration approach caught the attention of people, giving rise to the feeling of belonging over the building. The chapel was restored to daily life of those who live close

Figure 8: Restoration of the transept dome and interior walls.

Figure 9: Main façade after restoration.

Figure 10: View of the main altar from the choir.

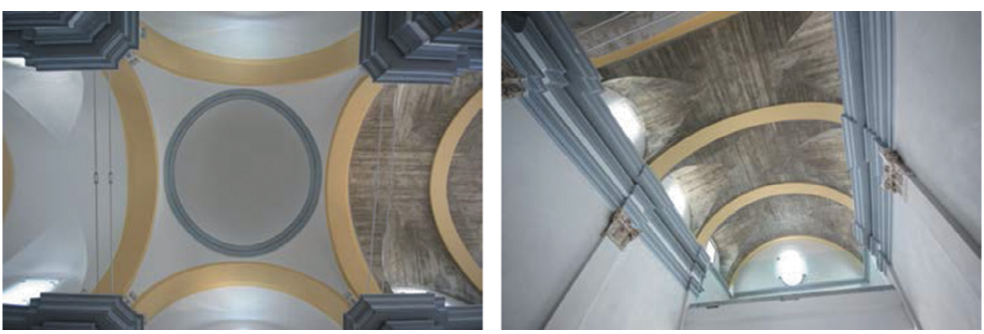


Figure 11: View of the dome and of the reconstructed vault.

by and reminded them how important is to invest time and money in historical heritage. The materials used, although modern in some cases, are less important than recovering a building that was almost lost (Figs. 10 and 11).

9 CONCLUSIONS

Interventions in ancient buildings could be extremely complicated if they are beyond restoration. One of the most difficult tasks is facing the significant challenges that arise due to the complexity of their geometry, materials and construction techniques, and the election of the techniques used for the restoration. This technical decision can have an influence over the position that the building has in the memory of those who live close by.

Showing modern materials used in restorations can value the still-standing part of the building and can make visitors identify how important heritage is. In the case of the Chapel of the Holy Sepulchre, restored and reconstructed parts work together as one, becoming a symbiotic solution so that inhabitants can recall the building that was once lost.

Recovering the chapel needed to combine two structures to make them work together. The use of reinforced concrete with a dual structural and a finished function enabled us to consolidate structurally complex and heavily damaged elements, while at the same time providing a visual historical record of the changes and reforms alongside subsequent interventions. In this sense, we consider this a sustainable technique that will enable future generations to learn about the various restoration works carried out on the building.

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